COST IMPLICATIONS of BUILDING DESIGN PLANS: a Literature Review Analysis

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***Abstract*—At the moment, the process of achieving awell-designed project in respect to cost constraints dictated by clients, both for private and public buildings isnot well understood.It involves a significant amount of re-design, and rework, thus take long to complete.In order to achieve a higher level of performance without an increase in product cost and time, it is necessary to identify, measure and articulate the major building design variables andtheir cost implications to a building project.Therefore, this literature review study has been sought to attain two objectives 1)identifying of building design variables and their cost implications, and then 2)make appropriate recommendations for the construction practitionersespecially in Indonesia. The literature was collected from wide range completed studies on the topic, critically examined and then results discussed, conclusions and recommendations drawn. The findings established 12 design variables, with main ones being plan shape and complexity, storey height, number of storeys, building size, and building services. Plan shape was identified to have the greatest impact on costs, with square shape being the cheapest while circular shape being most expensive, and complex shapes also having higher costs. The recommendations made were that there isneed for the building shape, to be as close as possible to square, avoiding irregular shapes. Further studies need to be done to establish how far individual cost elements are affected by these variables, especially in developing countries like Indonesia.**

***Keywords*—building design, plans, design variables, cost implications, cost elements and Construction industry**

I. INTRODUCTION

As the construction industry continues to be one of the fastest growing sectors of any economy, be it in developed countries or developing ones, the urge to deliver the best product output in terms of good designed building project, which is able to satisfy the clients and ultimate users cannot be over emphasized. This has again been added on to by the scarcity of resources and hence need to put the little available ones to the best use. This can be judged by having to incur costs which cannot be dealt away with, called value for money in projects. With this new phenomena, there is great tendency that most clients the common initial question they will ask is “what is it going to cost me?” often followed closely by “can we do it any cheaper?”[1]As according to Wikipedia, design is the creation of a plan or convention for the construction of an object or a system (as in architectural blueprints, engineering drawings, business processes, circuit diagrams and sewing patterns).

According to [2], [3], design is an iterative process through which a set of requirements such as; physical, aesthetic, performance, and so on are creatively manipulated, resulting into a design. In addition, design decisions form solutions to problems of function, form and economy for building [4].

Hence, this process, forms a complex interaction of skills, judgment, knowledge, information, and time[5], aimed at satisfying the client’s requirements through manipulations. In addition, it requires problem finding, and problem solving, deduction and the drawing of inferences, inductions and the creation of new ideas, analysis and synthesis.

In trying to find solutions for all these constraints encountered during the design process, the design team will always try to make adjustments on a wide range of issues, especially to do with how best the building project could be delivered, without compromising the performance and quality. This results into concept of modelling costs, according to [6] this is the different ways the project can be designed and constructed, with each method attracting different costs. Hence, the assessment of different design alternatives produce better solutions on achieving a particular project. These design combinations are the ones that have come be known as building design variables.

Previous studies into the area of design process have identified a great number of design variables, as models which account for the construction costs. They include, to mention but few: plan shape; building size; circulation space; perimeter to floor area; grouping of buildings; storey height and the total height or number of storeys for the building[7];[8]; [9]; [10];[11] and [12].

According to findings, perimeter-to-floor ratio unit construction costs and overall project costs are affected by variation in these design variables. In line with that forexample researchers have established that the more complex and irregular the building shape is the more expensive it is to construct. This is so because of constructability problems that come with complexity, plus increase in building elements like external walling with associated finishes like cladding, roofing, setting out costs, foundations, mechanical and electrical services among others.

As a result researchers have asserted that defining the right problem and then generate a range of possible solutions, inform of design variables, as one of the ways value management assists in reducing unnecessary cost [6]. This is because it eliminates a particular building component serving no real function or where costs are expended on unnecessary material. Hence, great need for more studies in the area.

However, much as many studies on the topic have been done, they are usually covering one specific area at ago, of design variable, therefore one of the problems there is isolation of the many design variables. Therefore this literature review analysis partly seeks to cover this. So the purpose/objectives of this concept paper review is 1) critically examine from the previous studies on the topic, the various building design variables, how their effect building costs, then 2) make recommendationsfor the construction industry in Indonesia.

II. RESEARCH METHODOLOGY

The study reported in this paper essentially was built upon an approach of, extensive focus-based literature search conducted on both printed and on-line materials of published and unpublished studies, with the purpose of identifying relevant studies concerning building design variables and their construction cost implications. Following this accomplishment, the literature was carefully reviewed and examined with the purpose of establishing general findings concerning the topic.

III. THEORETICAL FRAME WORK BUILDING DESIGN PROCESS

According to[13], in arriving at any particular design, there is a broad relationship between the client, shape, method and material of any construction, which is as follows; 1) The client determines the building shape; 2) The building shape determines the building material; 3) Material determines the structure and construction.

"Architectural form/plan is an inclusive term that refers primarily to a building's external outline or shape, and to a lesser degree references its internal organization and unifying principles" [14], while "Structural form is a building's primary or most visually dominant structural system" [14], of columnar, planar, or a combination of these which a designer can intentionally use to reinforce or realize ideas, that is mainly columns, walls and beams. To achieve any design there two attitudes/views towards structure that have been articulated in various periods of architectural history are:

A. Structure as form-follower

I*n other words, form is the initial basis and structure the necessary result.*

B. Structure as form-giver

Where *that the outward appearance of is an expression of an efficient structural or constructional reality, in other words, form must be the necessary result, and not the initial basis of structure"*[14].

During design, there are constraints that exist which are entirely internal to the system or object being designed, or may be linked with some external factors not under designer's control, has identified four types of constraints faced by designers during the design process, which are as: a) Radical Constraint , a range of healthcare policies fall under this; b) Practical Constraint, in other words, the constructability issue imposed by the design; c) Formal Constraint ; and d)Symbolic Constraint. As for [15], he simplified the constraints by grouping them into two broad categories; internal and external constraints.

During the whole of this process, of trying to put up solutions for economic related constraints, researchers in the field of construction economics have come up with models called building design variables, accounting for how costs of project are incurred.

A design variable is a numerical input that is allowed to change during the design optimization (making it perfect), or a parameter or unit of a building design that can be kept constant in a particular case, but which may be varied in different cases even while providing the same accommodation [16]. Hence, they form the morphological factors which influence the cost of building work. [7], they form designers' forecasts, as it is the building design variable that gives the information for forecasting and determining whether value can be achieved at an acceptable cost[17]. They also form a basis for decision making, as solutions to problems of function, form, time and economy for buildings [4]. This is because, they represent as closely as possible the way in which costs are actually incurred[18].

IV. RESULTS, ANALYSIS AND DISCUSSIONS

A thorough search of previous studies that have been carried by after reviewing have resulted into 12 number of major building design variables.

The generalbuilding design variables, which have been identified by the various studies are as shown in the table below together with some of the authors who have done studies on them:

TABLE I
THE IDENTIFIED BUILDING DESIGN VARIABLES AND PREVIOUS AUTHORS.
SOURCE: COMPILATION FROM ANALYSIS

No.	**Design Variable**	**Source/Authors**
A	Plan shape and Complexity	Seeley (1996)[19]; Ashworth (2004)[6]; Kouskoulas and Koehn (1974)[20]; Selley (1983)[4]; Staedman et al., 2009[21]; Wing, (1999)[22]; Ibrahim et al. (2015)[8]; Ibrahim, (2003)[9]; Ibrahim (2007); Seeley (1997); and Ferry and Brandon, (1999)[12]; Zima (2008)[23]; Zima and Plebankiewicz (2012)[24]
B	Size of Building:	Seeley (1997)[11]
C	Average Storey Height	Ibrahim (2003)[9]; Seeley (1996)[19]
D	Number of Storeys(Total Height)	Flanagan and Norman (1999)[25]; Clark and Kingston (1930)[26]; Stone (1963); Seeley (1996);

		Department of the Environment (1971); Thomsen (1966), Ferry and Brandon (1991)[12], Schueller (1986)[27]; Tregenza (1972)[28]; Steyert (1972)[29]; Tan (1999); Picken and Ilozor (2003)[30]; Ellen and Yam (2007)[31]; Lee (2005)[32]; Oss and Wamelink (2007)[33];Yau and Yeung (2007)[34]. Jong et al (2007)[33]; Chau et al (2007)[34]; Newton (1982); Warszawski (2003)[35].
E	Building Envelope	Seeley (1997)[11]
F	Circulation Space	Seeley (1996)[19]
G	Grouping of Buildings	Ashworth (1994); Abuza (2010); Seeley (1996)
H	Percentage of glazed (Cladding) wall	Swaffield and Pasquire (1996)[36]
I	Mechanical and Electrical Services Elements	Carroll (1982)[37]; and Kosonen and Shemeica (1997); Turner (1986);Aeroboe (1995) and Ellis (1996); Swaffield and Pasquire (1996)[36]; Bojic et al. (2002)[38]; Seeley(1996)[19]
J	Column Spacing	Seeley (1996)[19]; Ibrahim (2003)[9]
K	Floor Spans	Seeley 1996)[19].
L	Constructability	CIRIA (1983)[39]; Illingworth (1984)[40]; CII (1986); Tatum (1987); and Zainuddin (1997)[41]

The table above from the review, shows the highest number or researchers picking interest in mainly plan shape, total height of a building and services. This because of the extent of effect they have on the costs of individual elements. Hence, significantly costs expended on a number of building elements such as foundations, walls, building structure frame, greatly affected. For example [11] compared two buildings of rectangular and irregular shapes, each of which have the same floor area. Irregular shaped building where there is 6% more external walls to enclose the same floor area, setting out are increased by about 50% excavation cost about 20% and drainage cost by approximately 25%.

Another discovery was that, many based their studies on empirical data and mathematical regression studies and where carried out in developed countries like China, UK and USA among others, this is partly due to the level of competition in economies by high. For the nature or researches, this was due to the fact that to cost the data especially the cost data is not easy for researchers. Furthermore,majority of studies concentrated on how these design variables affect overall costs of a project, using cost per square meter (cost/m^2) data. Hence, less was found with researchers going as far as, establishing how alterations in these design variables affected the individual cost elements of substructure, block walling, roofing, windows and doors, finishes and decorations, electrical and mechanical services, maintenance costs (energy requirements of a building in relation to its maintenance). Some of identified studies that have gone deep in their analysis include [9] and [8].

Through the studies of construction economics of buildings, to reflect the effects of these design variables, researchers have provided ways to measure their effect through a number of building theories which include: W/F (Wall to Floor) index; LBI (Length/Breadth Index) index; PSI (Plan/Shape Index) index; Cook's JC (Cooke's JC shape efficiency) index; POP (Perimeter Over Plan) index; building planning "m" index; VOLM (Volume - block compactness) index; and Optimumenvelope area [12];[20], [12]; and [6].

V. EFFECTS OF DESIGN VARIABLES OF COSTS

Over the years, going by the findings of previous researchers, a great deal of cost implications these design variables have on the total costs of any construction project. This is because these variations in design variables, can go a long way in saving a great deal of materials and enabling constructability once they are paid attention to in detail, during design of any building project.

The general effects of the individual building design variables, identified from previous studies, are as shown in the table 2 below:

TABLE II
THE COST IMPLICATIONS OF DESIGN VARIABLES. SOURCE: RESEARCH REVIEW

No.	Design Variable	General cost implication	Accounting for the probablecost implication
1.	Plane shape	High perimeter-to-floor ratio high unit construction costs (Square is cheapest ratio of 1)	1.1 High quantities of finishes and decorations like paints and plaster.
			1.2 Increased volume of external enclosing block walling.
			1.3 Increased heat loss surface area.
			1.4 Change in foundation quantities
			1.5 Longer service and waste pipes
			1.6 Chances of extra doors & windows
2	Shape complexity	Irregular and complex shapes have higher the costs	2.1 High roof costs due to corners& material cutting wastages.
			2.2 Setting out costs& timeincrease.
			2.3 Excavation costs

			increase.
			2.4 Drainage costs high due to extra manholes and longer pipes
3	Size of Buildings:	Unit construction cost, such as cost per square meter reduce	3.1 Economical costs of preliminaries (as site offices, water supply, temporary roads costs etc.) are fixed.
			3.2 Greater economy in using lifts, bathrooms, staircasesetc.
			3.2 On costs and overheads form a smaller proportion of total costs
4	Average Storey Height	High construction costs for high storey heights	4.1 Increased volume of heating and longer lenghts of pipes or cables.
			4.2 Longer service and waste pipes to supply sanitary appliances.
			4.3 Higher roof costs due to increased hoisting
			4.4 Increased staircases and lifts' costs.
			4.5 Cost in applying finishes &decorations high working at high levels.
5	Number of Storeys	Generally there are cost items which fall as the number of storeys increases, those which rise, those which fall initially and then rise and those unaffected by height.	5.1 Foundation costs decreasing
			5.2 Beyond a certain number of storeys the form of construction changes and costs rise.
			5.3 Cost varies with the type, form and construction of the building.
			5.4 Air conditioning costs likely fall.
			5.5 Sophisticated equipment (wet or dry risers & sprinklers) increase.
6	Building Envelope	Simple envelope adopted (square shape) the more economical in total envelope	6.1 Lowest perimeter/floor hence cost expended on the walls & finishes plus the roofing low
7	Circulation Space	Lower space expended of circulation elements the more economical design is.	7.1 Associated costs on heating, cooling light and maintenance yet no profitable use, low.
8	Grouping of Buildings	I[8], [9], [11], [12]nter-linking buildings often results in savings in costs	8.1 Reduction in the quantities of foundations, external walling
9	Percentage of glazed wall	High wall to floor ratio results in higher costs	9.1 Due to glazing and cladding being a very expensive element of building
10	Mechanical & Electrical Services	Great proportion results building becoming costly	10.1 Since they costly elements
			10.2 They are biggest consumers of energy between up to 30% and 40%.
11	Floor Spans	Floor costs increase considerably with larger spans.	11.2 Floors and roof are the most expensive parts of a building structure
12	Constructability	The more constructability of any design plan becomes difficult the higher the cost implication	12.1 The complicated structures need specialized expertise
			12.2 Construction time increases where construct ability is a problem.
			12.3 Ease of compatibility of different elements once its well planned

The results shown in the table above, as discoveries from the previous researches verify why design/construction economics is taking center stage, during construction management, as opposed to designing where by architects took aesthetic requirements more important.

This practice, has necessitated the design consultants to have a complete understanding of the fundamental aspects of the user requirements for the project, and ability to compare the ultimate cost consequences of the construction work from different alternatives solutions [42]. Hence, avoiding the client paying undesirable costs from this complex and inappropriate design solutions during construction stage. Therefore, the industry is shifting more towards value for money in projects, what has come to be known as practice of value management or value engineering.

Furthermore, these previous studies indicate difference in the way construction costs of substructure, superstructure frame, walls, ceilings, floors, the roof, building services, finishes and the costs related to constructability due complexity like during setting out component plus energy costs, during maintenance, are affected [6]; [8]; [9];[10];[11]; [12].

In particular some of the studies that have tried to explore on how design variables affect costs are for example, [9] carried a more detailed study in the community of the Eastern Province of Saudi Arabia, using "Typical villa" (a villa that is representative of a community in terms of facilities, components' types and sizes, building materials and construction system). From this study, the results of his simulation were majorly that, given the same size of accommodation and quality of specifications, the simpler (more complicated) the building plan shape, the lower (higher) its cost per square meter GFA, and as the farther a plan layout tends from a square shape, the higher the perimeter to floor ratio, cost per square meter GFA and total construction cost; cost per square meter GFA increases with the average storey height of a building.

Furthermore, the shape layout that increases size of the building influences energy efficiency[23].

According to [19], one method of making a rough assessment of the additional cost resulting from an increase in the storey height of a building may be to work on an assumption that the vertical components of a building in the form of walls, partitions and columns account for certain percentage, say thirty per cent, of the total costs.

Finally, with Mechanical and Electrical Services Elements, as the other major design variables, studies revealed that commercial buildings are one of the biggest consumers of energy. In developed countries, buildings account for between 30% and 40% of the energy consumed [37]. Mechanical and Electrical (M & E) services can account for up to 60% of the cost of a modern building indicate that air-conditioning is responsible for between 10% and 60% of the total building energy consumption, depending on the building type.

VI. CONCLUSION AND RECOMMENDATIONS

The research review revealed that building designs can be realized in a wide range of alternatives, called design variables. 1) It has identified 12 variables with major ones being plan shape and complexity, storey height, building services and height of storeys, this is proved from the extent of attention researchers gave them and their cost implications that have been associated with them. Furthermore, each has its own unique way it affects costs. 2) A recommendation is made calling for more studies on the topic building design variables and their cost implications in the Indonesian construction industry. That is the building design considerations used by designers in Indonesia, parties involved and the cost impact they have on overall cost of a building project.

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